Strategic Decision-Making from the Perspective of Fuzzy Two-Echelon Supply Chain Model

Junzo Watada and Xian Chen

Abstract Game theory is applied widely to solving various problems to get optimal decisions. This paper analyzes the Stackelberg behaviors between a manufacturer and two retailers. As the market demand used to be uncertain, in order to describe the market demand fitting to real situations, this paper applys fuzzy variable in the two-echelon supply chain problem. Then, a numerical example is used to illustrate the result in comparison between fuzzy variable and crisp number. Fuzzy variable and crisp number are compared with mean absolute percentage difference rate of fuzzy demand (MAPDR-FD).

Keywords Two-echelon supply chain · Fuzzy variable · Optimal decision · Stackelberg

1 Introduction

Game theory becomes more and more common in the research on two-echelon supply chain and plays a pivotal role in optimal decision making.

We used to face how much amount to assign each of branches or of sections as a target amount in their region. The most important is the whole company's selling volume but on the other hand we have to encourage each of branches or of sections to work hard and obtain the best result.

In this paper, let us make a problem simplified. We have the manufacturing section M and two retailing Sects. 1 and 2. These three sections build a supply chain.In this case, there is a competition between the two retailing Sects. 1 and 2.

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In game situation, these two retailers 1 and 2 are Stackelberg situation. Therefore, when we give a leading position to 1, Sect. 2 will follows section A's initial decision. The objective here is to obtain their own best result in the Stackelberg situation.

Then, according to the best results of the two reailers got before, The manufacturer can know the decision made by retailers and decide the optimal assignment of price, amount, etc.

In order to solve this problem, let us consider the uncertain situation such as uncertain demand. This situation resulted in building a fuzzy two-echelon supply chain model.

In this paper, fuzzy variable is used in building model of two-echelon supply chain.

The remaining consist of the following sections. In Sect. 2, past research works will be shortly reviewed and Sect. 3 provides prereminary mathematical preparation for building a fuzzy two-echelon supply chain model. In Sect. 4 we define fuzzy two-echelon supply chain model and its solution based on Stackelberg game. Then, Sect. 5 discusses the numerical real-life problem of the stratgic decision-making of how to obtain the optimal assignment for each of the two retailer sections. At the end in Sect. 6 we summarize the paper as conclusions and explain the remaining problems.

2 Previous Research Results

In two-echelon supply chain, quantity, cost and price are key factors in order to get optimal decision. For example, Pui-Sze CHOW et al. [1] analyze the effect when taking a minimum order quantity (MOQ) in a two-echelon supply chain. Govindan KANNAN [2] uses multi-objective models in a two-echelon supply chain to optimize the total cost. Ilham SLIMANI and Said ACHCHAB [3] concerned with the optimization of the inventory and transportation in a supply chain. Y.A. HIDAYT et al. [4] analyze an inventory problem with only a single-supplier and a single-buyer. Cai Jian-hu and Wang Li-ping [5] analyze the influence of providing adequate pricing incentives before demand information is revealed. Geon Cho et al. [6] take a quantitative model when there is a partnership in supply chain. Daogang Qu and Ying Han [7] consider a single manufacturer and a single retailer model which has dual distribution. Longfei He and Jianyong Sun [8] consider a single vendor and a single retailer originated from China market background. CAI Jian-hu et al. [9] proposed an inventory model in a two-echelon supply chain. Yihong Hu and Jianghua Zhang [10] consider that when there is a price-only contract to a retail, how will be the manufacturer's reaction to a new-vendor. Fangxu Ren and ZhongYuan [11] analyze pricing and advertising model under equilibrium. Tiezhu Zhang and Longying Li [12] consider some contracts in order to get the win-win situation. Huilin Chen and Kejing Zhang [13] take the full-return coordination mechanism in consider. Fangxu Ren [14] considers the relation between the size of slotting allowance with the members' co-operation in a two-echelon supply chain.

Moreover, there are also many researches studying the demand function. Junping Wang and Shengdong Wang [15] study the effect to the chain members when the different forms of demand function are used. Jiang Meixian et al. [16] consider a model of coordinating pricing and express that the market demand is effected by retailer price and promotion expenses. Lau and Lau [17] analyze the difference of the optimal decision when facing the different demand curve in Stackelberg game situation.

3 Preparations

As the demand of the market is always uncertain. This paper takes the demand of the market as fuzzy variable so as to make the value more close to real situation. To illustrate the difference between the fuzzy variable and crisp number, Mean Absolute Percentage Different Rate of the Fuzzy Demand (MAPDR-FD) will be used.

3.1 Fuzzy Variable

Fuzzy Variable is defined as a function which has a possibility space $(\Theta, p(\Theta), Pos)$, where Θ denote a non-empty set, $p(\Theta)$ is a power set of Θ, and Pos is a possibility measure. The possibility measure satisfies the following conditions:

(1) $Pos\{\emptyset\} = 0$
(2) $Pos\{\Theta\} = 1$
(3) $Pos\{\bigcup_{i=1}^{m} A_i\} = \sup_{1 \le i \le m} Pos\{A_i\}$

By taking the triangular fuzzy variable $D = (a, b, c)$, the membership function is given as follows:

$$\mu(x) = \begin{cases} \dfrac{x-a}{b-a} & ; a \le x \le b \\[2ex] \dfrac{c-x}{c-b} & ; b \le x \le c \\[2ex] 0 & ; otherwise \end{cases} \tag{1}$$

Supposing A^c is the complement set of A, then the necessity measure of A is given as follows:

$$Nec(A) = 1 - Pos(A^c) \tag{2}$$

The credibility measure is denoted as

$$Cr\{A\} = \frac{1}{2}[1 + Pos(A) - Pos(A^c)]; \tag{3}$$

$$Cr\{A\} = \frac{1}{2}[Pos(A) + Nec(A)]; \tag{4}$$

Let D be a fuzzy variable. The expected value of D is give as follows:

$$E[D] = \int_0^{\infty} Cr\{D \geq r\}dr - \int_{-\infty}^{0} Cr\{D \leq r\}dr \tag{5}$$

When D is a triangular fuzzy number (a, b, c).

$$E[D] = \frac{a + 2b + c}{4} \tag{6}$$

3.2 Model Assumptions and Notations

This paper is to analyze the behavior of a supply chain with a manufacturer and two retailers.The assumptions and notations are given as follows:

Q_i: quantity ordered by retailer i, $(i = 1, 2)$;
c: unit cost of manufacturing;
w: the wholesale price per unit ;
p_i: the sale price by retailer i, $(i = 1, 2)$;
D_i: the demand of retailer i if prices are zero
Π_i: retailer i's profit $(i = 1, 2)$;
Π_M: manufacture's profit;
Π_i^*: retailer i's maximum profit $(i = 1, 2)$;
Π_M^*: manufacture's maximum profit

The downward-sloping demand function is defined as follows:

(McGuire and Staelin (1983) and Ingene and parry (1995) have used this type of demand curve with $a_i = 1$ successively). In this paper let $a_i = 1$. So the demand function is:

$$Q_i = (D_i - p_i + \theta p_j) \qquad (i, j = 1, 2) \tag{7}$$

where θ is the degree of substitutability between retailers.

4 Two-Echelon Supply Chain Model Based on Stackelberg game

In this Stackelberg game, we assume retailer 1 as a Stackelberg leader and retailer 2 as a Stackelberg follower. Then the profit function of retailer 1 and retailer 2 will be given as:

$$\begin{aligned} \Pi_{r1} &= (p_1 - \boldsymbol{w})Q_1 \\ &= (p_1 - \boldsymbol{w})(D_1 - p_1 + \theta p_2) \end{aligned} \tag{8}$$

$$\begin{aligned} \Pi_{r2} &= (p_2 - \boldsymbol{w})Q_2 \\ &= (p_2 - \boldsymbol{w})(D_2 - p_2 + \theta p_1) \end{aligned} \tag{9}$$

The reaction function of the retailer 2 is obtained by solving ($\frac{d\Pi_{r2}}{dp_2} = 0$):

$$P_2 = \frac{(D_2 + \boldsymbol{w} + \theta p_1)}{2} \tag{10}$$

Then retailer 1 knows the reaction function (4) of retailer 2 and substitute it into his profit function. Then the profit function of retailer 1 is as follows:

$$\Pi_{r1} = \frac{(p_1 - \boldsymbol{w})(2D_1 + \theta D_2 - 2p_1 + \theta^2 p_1 + \theta \boldsymbol{w})}{2} \tag{11}$$

To get the optimal price of retailer 1, setting $\frac{d\Pi_{r1}}{dp_1} = 0$, the function is obtained as follows:

$$P_1^* = \frac{(2D_1 + \theta D_2 - \theta^2 \boldsymbol{w} + 2\boldsymbol{w} + \theta \boldsymbol{w})}{[2(2 - \theta^2)]} \tag{12}$$

Then the maximum profit of retailer 1 is written as

$$\Pi_{r1}^* = \frac{(2D_1 + \theta D_2 + \theta \boldsymbol{w} + \theta^2 \boldsymbol{w} - 2\boldsymbol{w})^2}{[8(2 - \theta^2)]} \tag{13}$$

To get the optimal sale price and the maximum profit of retailer 2, the optimal sale price of retailer 1 can be substituted into reaction function of retailer 2. Then the function can be given as:

$$\begin{aligned} P_2^* = \Big(&2\theta D_1 + 4D_2 - \theta^2 D_2 + 4\boldsymbol{w} + 2\theta \boldsymbol{w} \\ &-\theta^2 \boldsymbol{w} - \theta^3 \boldsymbol{w}\Big) / [4(2 - \theta^2)] \end{aligned} \tag{14}$$

$$\Pi_{r2}^{*} = \Big(\theta^2 D_2 - 2\theta D_1 - 4D_2 + 4\boldsymbol{w} - 2\theta\boldsymbol{w} -3\theta^2\boldsymbol{w} + \theta^3\boldsymbol{w}\Big)^2 / [16(2-\theta^2)^2] \quad (15)$$

The profit function of manufacturer can be expressed as:

$$\Pi_M = (\boldsymbol{w} - c)(Q_1^* + Q_2^*) \quad (16)$$

$$\Pi_M = (\boldsymbol{w} - c)[D_1 + D_2 - (p_1^* + p_2^*) + \theta(p_1^* + p_2^*)] \quad (17)$$

Then the optimal price can be obtained by solving . $\frac{d\Pi_M}{d\boldsymbol{w}} = 0$,

$$\boldsymbol{w}^* = \frac{c}{2} + \frac{B}{(2J)} \quad (18)$$

where

$$B = 2[\theta + 2(D_1 + D_2)] - \theta[-2D_1 + \theta^2 D_2 + \theta(2D_1 + D_2)] \quad (19)$$

$$J = (8 - 4\theta - 7\theta^2 + 2\theta^3 + \theta^4) \quad (20)$$

So the maximum profit of the manufacturer can be given as follows:

$$\Pi_M^* = \frac{(8 + 4\theta + 3\theta^2 - \theta^3)(c - c\theta - D_1 D_2)}{16(\theta - 1)(2 - \theta^2)} \quad (21)$$

5 Numerical Examples

The numerical examples let us compare the difference of results between the fuzzy and non-fuzzy data sets. Setting $\theta = 0.5$ represents the moderate degrees of competition between two retailers (Table. 1).

Table 1 Assumed parameters

c	θ
2	0.5

5.1 Mean Absolute Percentage Difference Rate of the Fuzzy Demand (MAPDR-FD)

To find the difference between fuzzy and non-fuzzy data sets, the mean absolute percentage difference rate of the fuzzy demand is introduced. The formula is expressed as follows:

$$MAPDR - FD = \frac{100\,\%}{n} \sum_{k=1}^{n} \left\| \frac{\pi_k^l - \pi_{Fk}^l}{\pi_k^l} \right\| \tag{22}$$

where π_k^l is non-fuzzy value and π_{Fk}^l is fuzzy value $l = i, j, M$ and $k = 1, 2, \ldots, n$.

5.2 Fuzzy Variables

Let X_{D_1} be a fuzzy variable of demand faced by retailer 1. Assume $D_1 = (9, 19, 32)$

Let X_{D_2} be a fuzzy variable of demand faced by retailer 2. Assume $D_2 = (7, 18, 28)$

The possibility distribution of the triangular fuzzy variable are written as:

$$\mu_{D_1}(x) = \begin{cases} \dfrac{x-9}{10} & ; 9 \le x \le 19 \\ \dfrac{32-x}{13} & ; 19 \le x \le 32 \\ 0 & ; otherwise \end{cases} \tag{23}$$

$$\mu_{D_2}(x) = \begin{cases} \dfrac{x-7}{11} & ; 7 \le x \le 18 \\ \dfrac{28-x}{10} & ; 18 \le x \le 28 \\ 0 & ; otherwise \end{cases} \tag{24}$$

According to the possibility, necessity and credibility measures, the expected value can be calculated by using the following equation.

$$E[\xi] = \frac{a + 2b + c}{4} \tag{25}$$

The expected value of a triangular fuzzy variable can be calculated as:

Table 2 Fuzzy demand of market faced by supplier 1 and 2

	Fuzzy Triangular Number	Expected Value
D_1	(9, 19, 22)	19.75
D_2	(7, 18, 28)	17.75

5.3 Comparing the Results Between Fuzzy and Non-Fuzzy Data Sets

From Tables 2 and 3, it is easy to find that by using fuzzy data set, the profit of manufacturer is higher than the one without fuzzy data set. The quantity ordered by retailers using fuzzy number is more than the one using crisp number. On the other hand, the saleprices setted by retailers 1 and 2 using fuzzy number are lower than these using crisp number. When the fuzzy demand is less than crisp demand, the profit of retailer with fuzzy variable is lower than that without using fuzzy data set. On the other hand, when the fuzzy demand is greater than crisp demand, the profit of retailer using fuzzy data set is higher than that without using fuzzy data set.

In addition, the MAPRD-FD shows the difference between the fuzzy data set and crisp number data set.

As a result, in this situation, when the retailer sections are competitive with each other, the retailer 1 and 2 can get the optimal price and amount based on the stackelberg game analysis. According to the result, the manufacturer can also decide the optimal assignment of target price and amount. As the market demand is uncertain, we emloyed fuzzy variables in this calculation. Then we got the result that the quantity ordered by each of retailers 1 and 2 should be 0.09. The optimal profit of retailers 1 ,2 and manufacturer will be 0.483, 0.393 and 2.653. Then the profit shown in Table 3 each section can get the price and amount.

Table 3 The difference between fuzzy number and no-fuzzy data sets

	Fuzzy Data Set ($\times 10^2$)	Non-Fuzzy Data Set ($\times 10^2$)	MAPRD-FD
Π_{r1}^*	0,483	0.481	+4.30 %
Π_{r2}^*	0.393	0.451	–13.2 %
Π_M^*	2.653	2.588	+2.53 %
P_1^*	0.200	0.248	–19.2 %
P_2^*	0.187	0.240	–22.1 %
Q_1^*	0.090	0.060	+45.6 %
Q_2^*	0.090	0.070	+42.2 %

5.4 Real Life Problem

The data of Coca-Cola firm is analyzed to explain the different profit by using fuzzy and crisp number data sets.

Let X_{D_1} be a fuzzy variable of demand D_1 faced by LanZhou market.

$$D_1 = (1.174 \times 10^4, 2.098 \times 10^4, 5.269 \times 10^4) \quad (26)$$

Let X_{D_2} be a fuzzy variable of demand D_2 faced by XiNing market.

$$D_2 = (0.584 \times 10^4, 1.574 \times 10^4, 2.214 \times 10^4) \quad (27)$$

Then the possibility distribution of the triangular fuzzy variable can be written as:

$$\mu_{D_1}(x) = \begin{cases} \dfrac{x - 1.173 \times 10^4}{0.924 \times 10^4} & ; 1.174 \times 10^4 \le x \le 2.098 \times 10^4 \\ \dfrac{5.268 \times 10^4 - x}{3.171 \times 10^4} & ; 2.098 \times 10^4 \le x \le 5.269 \times 10^4 \\ 0 & ; otherwise \end{cases} \quad (28)$$

$$\mu_{D_2}(x) = \begin{cases} \dfrac{x - 5844}{9897} & ; 5844 \le x \le 15741 \\ \dfrac{22140 - x}{6399} & ; 15741 \le x \le 22140 \\ 0 & ; otherwise \end{cases} \quad (29)$$

The same as above, according to the possibility, necessity and credibility, we can get the expect value. the results are shown in Tables 4 and 5.

Table 4 Fuzzy demand faced by LanZhou and XiNing market

	Fuzzy Triangular number ($\times 10^4$)	Expected Value value ($\times 10^4$)
D_1	(1.174,2.098,5.269)	2.660
D_2	(0.584,1.574,2.214)	1.487

From Table 5, we can get a conclusion that by using fuzzy number the profit of the manufacturer is higher than using crisp numbers. When the fuzzy demand is less than crisp demand, the profit of retailer using fuzzy variable is lower than use crisp numbers. On the other hand, when the fuzzy demand is greater than crisp demand, the profit of retailer using fuzzy variable is higher than use crisp numbers.

Table 5 The difference between the fuzzy number and no-fuzzy number

	Fuzzy Data Set ($\times 10^6$)	Non-Fuzzy Data Set ($\times 10^6$)	MAPRD-FD
Π_{r1}^*	97.0	60.0	+60.0 %
Π_{r2}^*	28.0	34.0	–16.1 %
Π_M^*	300	251	+19.7 %
P_1^*	0.290	0.320	–8.00 %
P_2^*	0.240	0.290	–18.1 %
Q_1^*	0.092	0.038	+142 %
Q_2^*	0.053	0.020	+162 %

The saleprices setted by retailer1 and 2 using fuzzy data set are lower than these using crisp number. On the contrary, under the fuzzy demand environment, the quantities ordered by retailers1 and 2 are more.

From the stackerberg game analysis, we can get the optimal assignment of price and amount. As the demand is not uncertained, we employ fuzzy variable to describe it. It is easy to find that though saleprices setted by retailers using fuzzy data set are lower than these using crispe number, the quantities ordered by retailers under fuzzy demand enviroment are more than using crisp number. As the profit by using fuzzy data set is higher, it is more benifit for manufacturer to use fuzzy data set. We can also find that the the more the profit is, the bigger the difference between using the fuzzy data set and crisp number.

To simplify the real problem, this paper analyse the bahaviors in a duopolostic situation. The result showed in the table is not affected by other manufacutures. So this result is different from the real environment, but we can surely know that by using fuzzy data set , the profit of manufacuturer is more than using crisp number.

Moreover,according to the MAPRD-FD, the degree of difference by using the fuzzy number and no-fuzzy number can be calculted.

In conclution, we regard retailer 1 as the leader and retailer 2 as the follower, after doing the analysis based on stackelberg game, then we can get the optimal amount and price shown in Table 5. The quantity ordered by retailer 1 and 2 should be 9,214 and 2,027 respectivly. Also, the optimal decision of manufacture can be gotten. As the market demand is uncertain mentioned before, fuzzy variables will be employed in this real life problem. Then we can finally get the result that the profits of retailer 1 2 and manufacturer are 97, 28 and 300 million USD. In this paper, many factors are ignored. By simplifying the real situation, we discussed the effect of fuzzy demand and non-fuzzy demand under the simplified situation as portion 3 mentioned. In order to get their largest profits, the manufacturer and retailers will make decisions as above. So under the fuzzy demand conditions, they will get more profit. However, in the real situation, without any contract between the retailers, the retailers will be competitive with each other. So in order to expand the market demand, the retailers always reduce the price until the Nash Equilibrium is gotten. In this paper, we only take the first situation into consideration. And as a result, we can know the difference between the fuzzy demand and non-fuzzy demand.

6 Conclusions and Future Work

In this paper, the competitive between a manufacturer and two retailers are shown. The stackbelberg game always be used to solve this problem in order to make a best decision. By using the fuzzy variable, the profit of the manufacture will be higher than the one which use crisp number.

This paper analyse a manufacturer and two retailers. As the future work, to analyse the market more accurately, there are more retailers need to be considered. Facing the market demand using fuzzy variable, the best decision of the manufacture and retailers should be discussed.

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